An analysis of car chassis

Contents

1.0 Introduction

My analysis of car chassis structures began as part of my interest in building my own car. I decided to do my own analysis of car chassis as there are very few sources of information that explain the design issues facing the amateur chassis builder. The aim of my analysis was to help design capable chassis that an amateur builder could realistically attempt to make.

My analysis is based on simple finite element analysis. This method is used by major car manufacturers to help design and assess their chassis designs. My models are intended to represent the main load bearing components of a chassis. The effect of minor brackets, the drive train, and other parts or regions of the car that make little difference to the basic chassis structure are not included. Panels attached by rivets are not included as rivets can work loose over time and lose their structural capability even though they may still be perfectly adequate to support non structural panelling. The results of my analysis will consequently be different to a real chassis. The quoted results for stiffness and weight should still be reasonably close to reality and adequate for showing the effect of design changes.

Please note that the information given in chapters 8 and 9 is copied from the Internet and that I have not fully checked it.

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2.0 General results for space frames and ladder frames

The basic way of assessing a chassis design is to establish its torsional stiffness. A high stiffness usually indicates a good chassis design.

The advantage of a properly designed space frame is probably about five percent or less, in weight and stiffness for the complete car, over an equally well designed simple X braced ladder frame. A more complex space frame with fully triangulated front and rear suspension regions, engine bay and sill structures will give a bigger advantage but will be harder and more expensive to make. This difference is important for race cars especially when the skills to produce a good design are available. However for most road cars and some race cars a ladder frame would be perfectly adequate. If a space frame chassis does not have enough bracing in the correct places in the form of diagonals or welded in panels then the stiffness advantage is reduced. This is why many space frame chassis are not as good as ladder frame chassis of the same weight.

Space frames have an additional advantage in both weight and complexity where the chassis panelling forms a significant portion of the bodywork as on many Seven type cars. This maximises the advantages of a space frame by removing the need for the extra weight and complication of additional bodywork and the extra structures needed to support it.

The most common mistakes for space frames are absence of sufficient triangulation or panelling around the front suspension region and the engine bay. Poor triangulation or panelling of the rear suspension region and engine bay is common on mid engined cars. Poor triangulation or panelling of the transmission tunnel is common on front engined cars.

Ladder frames have advantages that are often overlooked. Access to mechanical parts is often better and engine intake and exhaust systems are less likely to be restricted by the need to route them around chassis tubes. The number of tubes required is less than for a space frame and welding is easier due to the thicker steel usually used for ladder frames. Additional structures are often required with ladder frames to support bodywork but these can often be designed to brace the basic chassis structure.

For a panel to be structural it should be a welded in steel panel. Panels should be stitch welded or, preferably, continuous welded by stitching twice, the second time to fill in the gaps left the first time. Riveted panels can work loose over time and should not be relied on for strength or where safety is important. This statement is intended to apply to amateur built chassis and not to designs where riveted aluminium panels have been proven to be acceptable.

Some production cars use aluminium chassis which are often described as space frames. None of these are true space frames and most of them are closer to ladder frames in overall concept.

3.0 The Locost Chassis

The following information is a summary of my analysis of the chassis design presented in Ron Champion's book "build your own sportscar for as little as £250" which contains plans for a "Seven" type of chassis. The chassis modifications necessary to make big improvements in many space frames are simple. My results show that this can be possible without an increase in weight or complication.

Note that these figures only take into account the basic welded steel structure of tubes and panels and are subject to the usual differences between builds and the inaccuracies inherent in the simple analysis used. Alloy panels and other bolted, bonded or riveted on bodywork will increase the stiffness. Panels are assumed to be continuously welded in place by stitch welding twice, the second time to fill in the gaps left the first time.

This is our starting point.

Chassis by the book with 16 gauge sheet steel panels
Stiffness is 1180 ftlbs per degree of twist
The weight is 181 lbs.
With a welded on dashboard structure and considering some of the possible variations in the book the stiffness could be about 1400 ftlbs per degree of twist.

The simplest option to increase chassis stiffness, which is in the book, is to weld in a steel panel between tubes E and LD. If this is done then we have the following.

Chassis by the book, including optional front panel, with 16 gauge sheet steel panels
Stiffness is 1301 ftlbs per degree of twist
The weight is 184 lbs.
With a welded on dashboard structure and considering some of the possible variations in the book the stiffness could be about 1500 ftlbs per degree of twist.

This is how to up rate the Locost chassis from the initial starting point given by the book chassis.

All of the tubes in the original design remain as in the book. The extra tubes are assumed to be 1 inch square with 16 gauge wall thickness. All of the steel panels, except for the seat belt mount reinforcements and rear suspension mount reinforcements, are 18 gauge. This change in the panel thickness gives a worthwhile weight saving.

Form a V joining the centre of tube LC to the ends of tube LD. This triangulates the front with the tubes running immediately behind the radiator. The reduction in airflow will be minimal. If radiator, fan or water pipe clearance is a problem then a diagonal or X brace across the chassis in this position may be used. Alternatively a similar modification connecting the ends of tubes FU1 and FU2 may be used but may cause clearance problems with the front of some engine ancillaries. A front V brace adds two tubes to the chassis.

Form two diagonal braces, one on each side of the chassis, between the tops of tubes LA and LB and the bottoms of tubes FU1 and FU2. This carries the triangulation of the chassis sides right to the front of the chassis and crosses the rectangular hole in each side of the chassis roughly defined by the top and bottom wishbone mounting points. Check that there is room for the steering rack. The braces add two tubes to the chassis.

Some Locost builders have reported that the floor can flex when thin gauge steel is used. Floor reinforcing tubes, running parallel to B2 and just in front of or under the front of the seats may be welded in, one on each side of the car. This adds two tubes to the chassis.

Weld in a panel across the bottom of the chassis between tubes E and LD. The book gives this as optional. The alloy panel referred to in the book contributes little to the chassis.

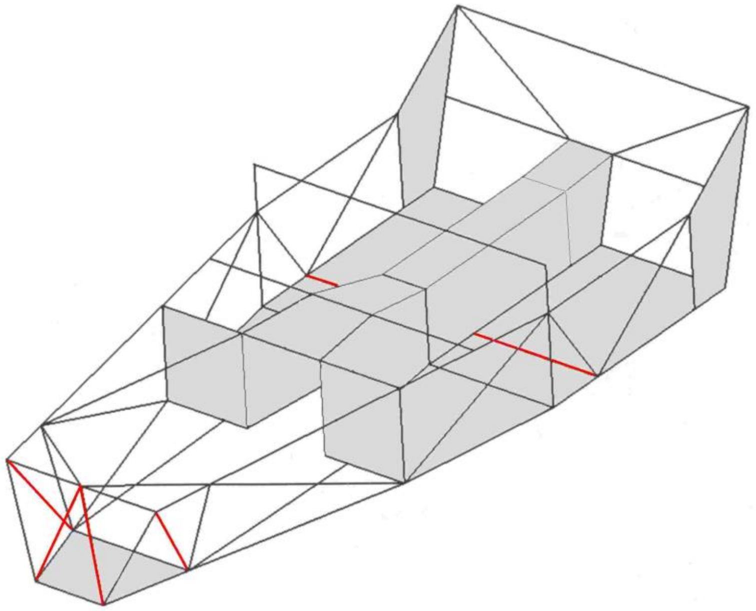
The next step is to box in the transmission tunnel from tube O3 to tube P. This makes the transmission tunnel into a welded 18 gauge steel tube enclosed on the sides, top and bottom. A hole for the gearlever will be required. A hole for the handbrake will also be required unless you decide to mount the handbrake under the dashboard as on the Caterham Seven

If you intend to establish the length of the prop shaft as described in the book then you will have to leave the tunnel unfinished until after the prop dimension is taken. For final assembly it should be possible to feed the prop spline onto the gearbox spline as the area beneath the gearbox, in front of tube B2, is not panelled. The prop shaft may need to be fixed to the diff during final assembly as the rear prop shaft flange may be inaccessible in the finished boxed in tunnel.

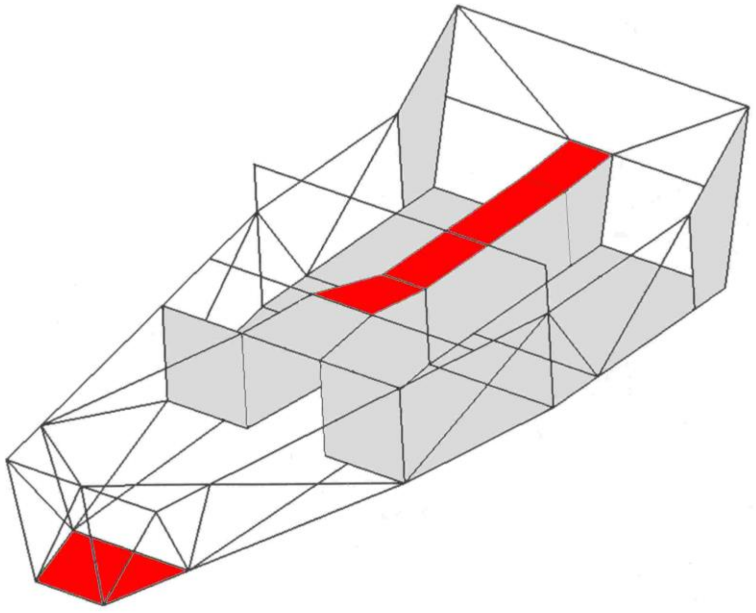
The ¾ inch tubes forming the frame of the transmission tunnel do nothing if this modification is done and we can therefore take an opportunity to reduce weight. Delete tubes c, d, g, h, i, j, the two rear k tubes and the tube which connects the tops of the two rear k tubes. A single arch over tube B2 may be required to give local reinforcement to support the handbrake or gearshift mechanisms hence the retention of the front k tubes and the tube that connects their tops. Check a Caterham chassis if you find it hard to believe that tubes may be removed, it has a very light structure in this region indeed. This step removes a total of nine tubes from the chassis.

The pictures do not show the luggage area but this is included in the analysis and in the weight calculations.

The picture shows the extra tubes.



The picture shows the extra welded in panels.



We now have a good all round improvement for not much effort:

The result is a chassis with a modified front, 18 gauge sheet steel panels and a boxed in tunnel with no internal ¾ inch tubes except for a front hoop and the floor braces.

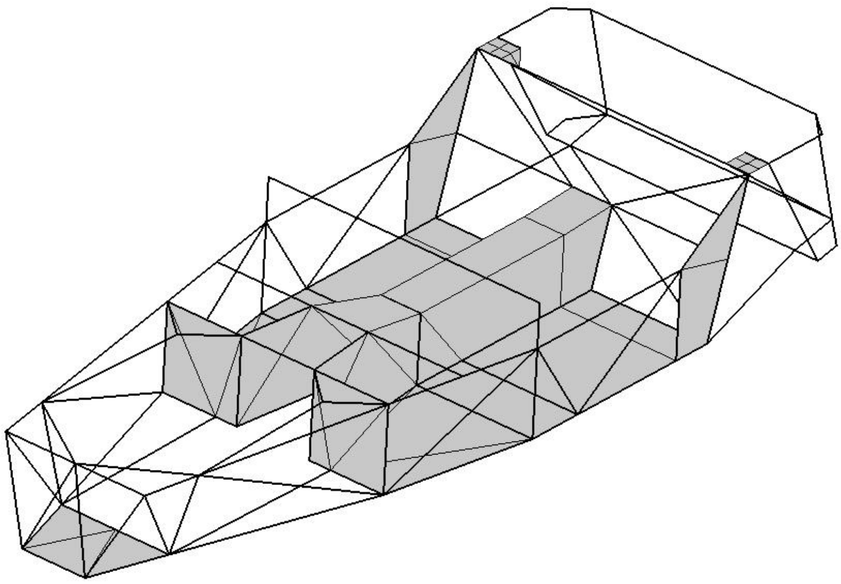
The stiffness is 2541 ftlbs per degree of twist and the weight is 171 lbs

Note that the weight is lower, the stiffness much higher and the number of tubes is reduced by three compared to the basic chassis built to the book. This shows that extra stiffness need not mean extra weight or complication.

If a Satchel link is used to locate a live axle or De Dion axle or if an independent double wishbone suspension is used then the tubes around the back of the transmission tunnel will need to be stronger than ¾ inch and should be 1 inch square as a minimum.

The best stiffness is achieved with an additional modification to the engine bay. Delete tube R and replace it with two Y braces. This has the advantage over using two R tubes, on both sides of the engine bay, of providing more space to accommodate bigger engines. The normal way of accommodating a large engine is to use one or two short engine bay diagonals that do not extend to the front of the engine bay but instead join the tubes on the sides of the engine bay. The double Y brace arrangement is show below and is superior to any arrangement using one or two short diagonals though it is slightly more complex.

The double Y braced chassis, with all the extra diagonals, a modified transmission tunnel and reduced panel thickness has a stiffness of 2683 ftlbs per degree of twist for a weight of 174 lbs. This requires only two extra tubes compared to the book chassis and is ten pounds lighter.



There are errors in the Locost book plans. These affect the front suspension region. Check the Locost book errors section for more information about this issue.

4.0 Larger engines in the Locost chassis

The standard book chassis was originally designed for small Ford engines. The book refers to engine sizes of 1100cc and 1300cc with the occasional reference to 1600cc. My high stiffness modifications or another equivalent set of modifications to improve stiffness should bring improvements for all engine sizes. For larger engines further changes are advisable.

Tube R is important!

Do not remove tube R to make room for large engines as this tube has a large influence on chassis stiffness. The simplest solution to gaining more width in the engine bay is probably to make two Y shaped structures, one on each side of the engine bay, as follows. Add two tubes running straight back from the outer ends of tubes S and T to about 6 inches from the footwell ends. Add short diagonals from the rear ends of these tubes to the top corners of the footwells. Using two short R tubes is not very good.

The effects of changing tube R on the book chassis are as follows.
Book chassis 1155 ftlbs per degree of twist
Two short R tubes 907 ftlbs per degree of twist
Two Y braces 1215 ftlbs per degree of twist

Slightly bigger engines: 1.6 to 2.0

For slightly larger engines than the book design, about 1.6 to 2.0 litres, tubes TR1 and TR2 begin to become unsatisfactory. This is more to do with these tubes being long and thin, and therefore tending to bend under load, than their actual size. Other tubes also benefit from changes. I would suggest increasing the sizes of some of the tubes as follows.
TR1 and 2
14gauge 1inch diameter or 16gauge 1 inch square minimum
TR3, 4, 5 and 6
16gauge 1 inch square
C, G1, G2 and E
16gauge 1 x 1.5 inches (one and a half inches deep) It may be easier to connect tube G1 and G2 to the ends of tube E
R, J1, J2, N1 and N2
14gauge 1 inch square or 16gauge 1 x 1.5 inches (one and a half inches deep)

Large engines: 2.0 to Rover V8

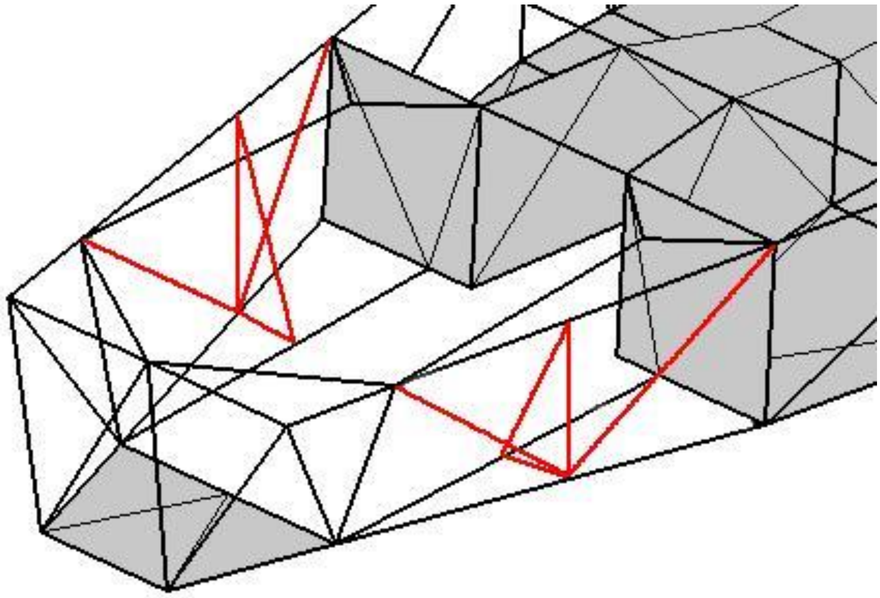
For bigger engines than 2.0 litres further modifications are required. I suggest the following.
The book chassis stiffness is becoming marginal at this performance level so use my high stiffness modifications or another equivalent set of modifications to improve stiffness.

Replace tube R with two Y braces as described above.

Replace TR1 and TR2 with a new arrangement as follows.
Add a vertical tube on each side of the engine bay from the engine mount positions on tubes F1 and F2 to tubes J1 and J2.
Add two new diagonals on each side of the engine bay from the bottom of the vertical tubes to the tops of FU1 and 2 and the tops of tubes H at the ends of tube Q.
Replace the engine mount plates with tubes connecting F1 to G1 and F2 to G2.
Add tubes from the inner ends of the F to G tubes to the top of the new vertical, F to J, tubes. These tubes are to support the engine mounts.

These changes are shown in the picture below.

Increase the sizes of some of the tubes as follows.
TR3, 4, 5 and 6
16gauge 1 inch square
C, G1, G2 and E
16gauge 1 x 1.5 inches (one and a half inches deep) It may be easier to connect tube G1 and G2 to the ends of tube E.
R, J1, J2, N1 and N2
14gauge 1 inch square or 16gauge 1 x 1.5 inches (one and a half inches deep)
Change the size of K1 and 2 to 14gauge 1 inch square or 16gauge 1 x 1.5 inches (one and a half inches deep)



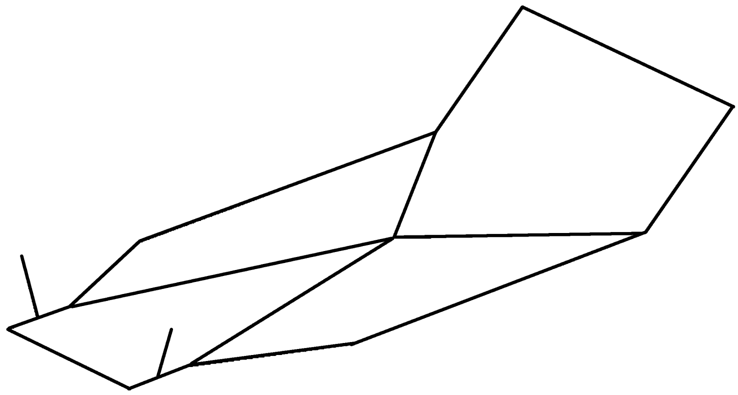
One important point is that the front lower wishbone is very highly loaded. The book specifies a three quarter inch tube which is only suitable for smaller and lighter engines. I suggest that one inch tubes would be better. This is a simple change to the book design. There are two further changes that will improve the wishbone design but these will involve significant alterations to the design and you may wish to avoid them to keep your build simple.

If you redesign the wishbone then there are two changes that will improve the design. The book design has a distance from the lower hub pivot to the spring mount of 4.3 inches. A smaller distance is better. Some designs have a distance from the lower hub pivot to the spring mount of about two inches. The best shape for the wishbone is a V shape. The tubes of the book wishbone do not form a V shape. The tubes should be positioned on a line connecting the chassis bush centres with the lower hub pivot. In the book the tubes are offset at the outer ends to allow for the width of the lower ball joint mounting plate.

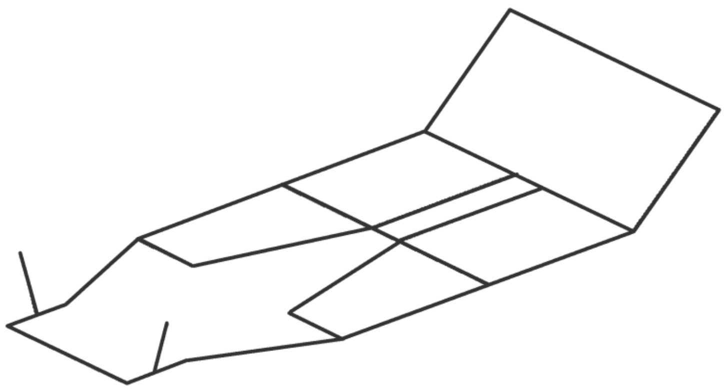
5.0 Regarding ladder frames

The pictures below show a simple ladder chassis with X bracing and with non-X bracing. The analysis of this design assumed chassis members of two inch width by four inch depth RHS with one-eighth inch wall thickness. The front springs are mounted on upright turrets and the rear springs are mounted at the ends of the rear cross member. The rear of the chassis rises to clear the rear axle as in most ladder frames.

The X braced chassis weighs 172 lbs and has 2358 ftlbs per degree of twist while the non-X braced chassis weighs 191 lbs and has 2066 ftlbs per degree of twist.



An significant factor for good X bracing is taking the arms of the X as close to the suspension mounts as possible.



Though both chassis would be adequate for a light weight car the X braced frame is stronger, lighter and simpler.

An X braced ladder frame for a Seven type car with side beams following a similar profile to a Ford model B chassis, as found under many hot rod cars, made of 100 x 50mm with 2mm wall box section tubes would weigh about 140lbs and have a torsional strength of about 1400ftlbs per degree of twist. Additional structures would be required to provide support for the body work, seat belt mounts, dashboard and other parts but these could be designed to add strength to the chassis. Overall the chassis would probably result in a car about 5 to 10 percent heavier than a typical Locost with a torsional strength between the original space frame chassis and my modified space frame chassis.

A panelled footwell and dashboard structure welded to the main side rails is good and bracing this to the front suspension region is also good. Some Cobra replica chassis make good use of this approach.

A suggested ladder frame tube size for a light weight car is 100 x 50mm with 2mm walls. It is relatively simple to design a ladder frame of this material that is very close to, or better than, many space frames. Most ladder frames use 3mm wall thickness steel sections for main rails which results in a relatively heavy chassis.

6.0 A list of chassis analysis and quoted results

Here is a list of torsional stiffness values. As for the Locost analysis these figures only take into account the basic welded steel structure of tubes and panels and are subject to the usual differences between builds and the inaccuracies inherent in the simple analysis used. Alloy panels and other bolted, bonded or riveted on bodywork will increase the stiffness.

Lotus 23 replica
The stiffness is 1449 ftlbs per degree of twist and the weight is 100 lbs.
This assumes round 1 inch dia 16 gauge tubes

Cobra ladder frame using 100 x 50 x 3 mm rails, substantial footwell and dashboard structure and panelled in transmission tunnel
The stiffness is 4785 ftlbs per degree of twist.

Cobra ladder frame as above but using 80 x 40 x 3 mm rails
The stiffness is 2865 ftlbs per degree of twist.

Simple X braced chassis using 100 x 50 x 3 mm rails with no other reinforcing structures for cars with full width bodywork such as a Cobra type car.
The stiffness is 3656 ftlbs per degree of twist and the weight is 200 lbs.

Simple X braced chassis using 100 x 50 x 2 mm rails with no other reinforcing structures for cars with narrow, Seven or Duce hot rod style, bodywork (the thin tube walls are to avoid an excessively heavy chassis on a seven type car)
The stiffness is 1400 ftlbs per degree of twist and the weight is 133 lbs.

Lancia Stratos replica
The stiffness is 6579 ftlbs per degree of twist and the weight is 300 lbs.
Claimed stiffness value when tested by STATUS was “over 6000”

Book claim for Morris Minor
The stiffness is 4000 ftlbs per degree of twist.

Book claim for original Lotus Elan backbone chassis with bodyshell mounted
The stiffness is 4300 ftlbs per degree of twist.

Magazine article claim for Lotus Elise
The stiffness is 7350 ftlbs per degree of twist.

Internet forum claim for the Ultima Coupe
The stiffness is 3300 ftlbs per degree of twist and the weight is 300 lbs

Magazine article claim for sports saloon
The stiffness is 13000 ftlbs per degree of twist.

A guideline is that the chassis torsional stiffness, in ftlbs per degree of twist, should equal the total car weight in pounds for a road car. For a race car the stiffness should be double the value obtained by this calculation. Many amateur built race cars have a road car chassis stiffness according to this rule. This shows that other factors can still be important.

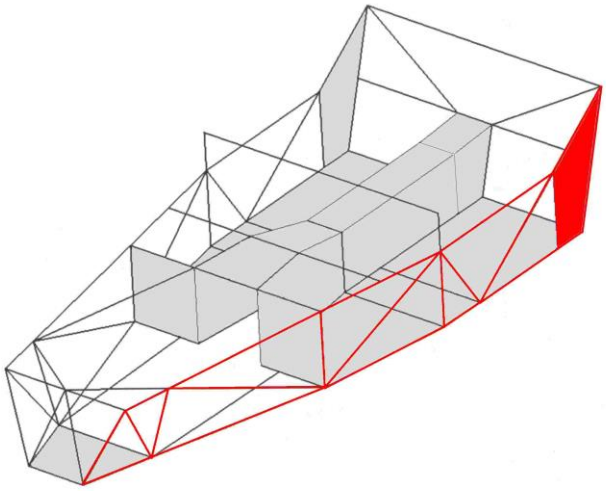
Hybrid chassis, combining elements of ladder frame, space frame, backbone and monocoque, are often very good. Consider a rally car based on a production monocoque, which contains elements of ladder frame and monocoque in the sills and floor regions and backbone in the transmission tunnel, braced by a space frame roll cage and strut braces to produce a very stiff structure. Similarly the Stratos, original and replicas, could be considered a monocoque and space frame hybrid and the Elise could be considered a ladder frame and monocoque hybrid.

7.0 A design checklist for space frames and ladder frames

The following information is a basic check list for chassis design with regards to torsional stiffness.

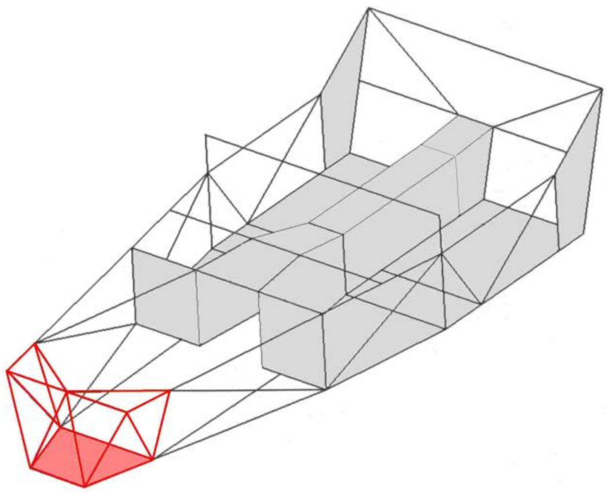
1) Space frame chassis sides

When viewed from the side a space frame should look like a network of triangles from the rear suspension region to the front suspension region. Small local variations are acceptable and alternatives to simple diagonal bracing include X, V and Y bracing and welded in panels. The picture shows diagonal bracing and welded in panels on the side of the modified Locost chassis. It is possible that a chassis that fails on this account will still be acceptable if the main longitudinal tubes are strong enough for it to be considered as a ladder frame.

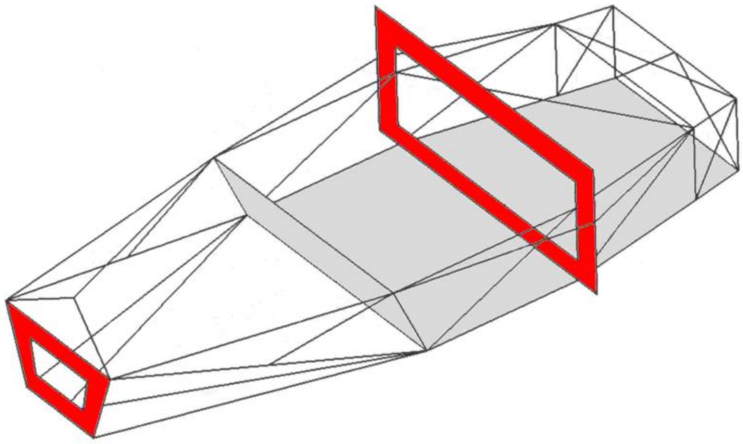


2) Space frame chassis suspension mounting regions

Space frames should have diagonal, X or V bracing or welded in panels on the front, back, top, bottom and sides of the chassis region between the front wishbones. The ideal structure in this region is a box with the wishbone mounts at the corners and triangulation or welded in panels on every side. It may not be possible to brace all six sides of this chassis region but this does have a significant influence on chassis stiffness. The picture shows the bracing in this region for the modified Locost chassis. The rear of the region shown in the picture is not braced due to the need to clear the front of the engine.

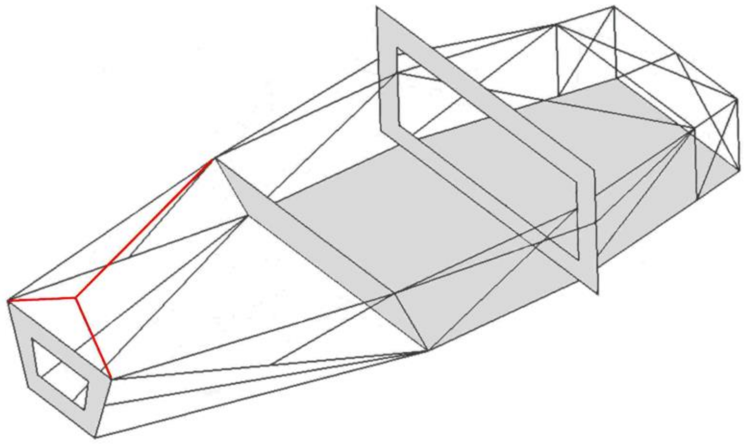


The rear suspension mounting regions of a space frame chassis should also be reinforced with diagonal bracing. The diagonals should go across the car as well as along the chassis sides. An alternative form of bracing for mid engined cars is shown in the next picture. A panel with a central hole for the gearbox, gear linkage and exhaust pipe is used. The outer edges and inner hole edges of the panel need to be stiffened by welded on tubes. A panel of this type is used on the Lotus 23 replica chassis shown in the picture. A mid engined car with a plain, unbraced, hole in the structure connecting the back of the chassis is likely to be poor.



3) Space frame chassis engine bay

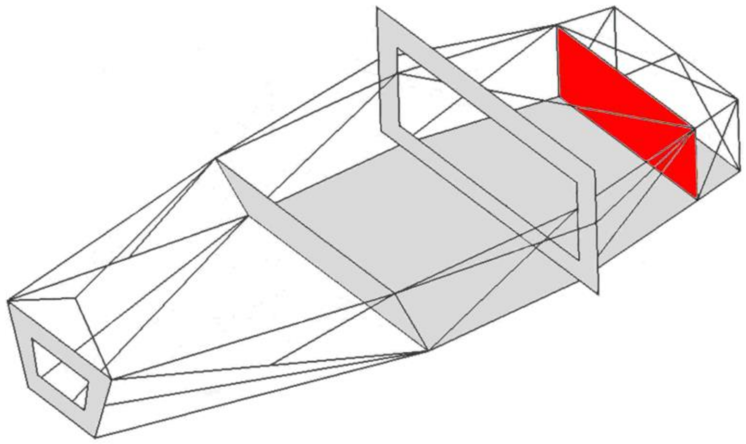
Reinforcement of the engine bay is important. Space frames should have at least one diagonal or Y brace on the top of the engine bay. A single Y brace is shown in the picture of a Lotus 23 replica chassis. The Locost book plans show a single diagonal, tube R. This reinforcement of the engine bay is important. An alternative design applicable to mid engined cars with wide engine bays is to have diagonals running outside the engine bay from the rear suspension region to triangulated sill structures on the sides of the chassis. This is not as good but is common on many designs.



Space frames should also have reinforcement on the bottom of the engine bay. The bracing can be diagonals at each side of the engine or an X or V brace. The Locost book plans show two tubes, G1 and G2, in this position.

4) Space frame and ladder frame footwells

Joining the front suspension region to a load carrying footwell and dashboard region is very effective. This applies to space frame and ladder frame designs. One way of doing this on a mid engined space frame design is to fit a welded in panel across the rear of the suspension region and the end of the footwell. The picture shows how this would look if applied to the Lotus 23 replica chassis. This chassis would require further modifications to restore the footwell length if this was done.



For ladder frames a panelled footwell and dashboard structure welded to the main side rails is good and bracing this to the front suspension region is also good. This is a feature of some cobra chassis.

5) Panelling space frame chassis

A thin welded in steel panel is often just as good as a riveted aluminium panel with a chassis diagonal tube. It can also be simpler and cheaper and may last longer. For a panel to be structural it should be a welded in steel panel. Panels should be stitch welded or, preferably, continuous welded by stitching twice, the second time to fill in the gaps left the first time. Riveted panels can work loose over time and should not be relied on for strength or where safety is important. Riveted floor panels on some space frame chassis can fall out. This statement is intended to apply to amateur built chassis and not to designs where riveted aluminium panels have been proven to be acceptable.

6) Bracing ladder frames

For ladder frames an X brace or K brace is good. The diagonal arms of the X or K should end near to where the suspension loads are fed into the chassis. If the angle of the arms of the X or K relative to the car centreline are outside 25 to 50 degrees then the effectiveness will be reduced. Angles less than this may be unavoidable in a front engined car where the front arms of the X cross the engine bay region. The centre of the X or K brace is highly loaded and should not have any holes or sections removed to make room for transmissions, gear linkages, cables or other parts.

7) Tube size and strength

If the wall thickness of a tube is increased then the ability to support bending loads increases by the same amount. If the wall thickness is doubled then the ability to support bending loads is also doubled.

If the size of a tube is increased then the ability to support bending loads is increased by the square of the increase in size and the tube stiffness is improved by the cube of the increase in size. If the diameter of a tube is doubled then the load carrying ability for bending loads is improved four times and the stiffness under bending loads is increased by eight times.

Due to these effects larger sized tubes with thinner walls are usually better than smaller thick walled tubes of the same overall weight. This is more important for ladder frame chassis than for space frame chassis. The following table shows how beam stiffness, torsional stiffness and weight changes when tube size changes.

Height x width x wall inches	Change in Bending stiffness	Change in Torsional stiffness	Change in weight
4 x 2 x 1/8	Original stiffness	Original stiffness	Original weight
2 x 1 x 1/8	89% reduction	89% reduction	52% reduction
5 x 2.5 x 1/16	5% increase	7% increase	36% reduction

The second beam in the table shows that halving the external size roughly halves the weight but reduces both stiffness ratings by 89%. The third beam in the table shows that with a slightly larger external size and half the wall thickness the stiffness values are slightly greater and the weight is reduced by about a third.

8) Alternative materials for chassis

Steel tubing is probably the best material for an amateur built space frame chassis. If aluminium tubing is used then the chassis weight will be only one third of the weight of a steel chassis. The stiffness and strength of the chassis will also be only one third of the steel design. The stiffness and strength can be improved by making the tubes bigger but then the chassis weight is increased. It is actually theoretically impossible for a true space frame to be torsionally better or worse in aluminium than in steel for the same weight and similar external tube sizes.

For ladder frames aluminium offers the potential to give good results. If a steel beam is replaced by an aluminium beam that is 25% bigger in width and height and has 50% greater wall thickness then the stiffness will be the same as the steel beam but the weight will be 45% less. An example of this would be changing a rectangular steel section 4 inch by 2 inch with 14 gauge wall thickness for an aluminium section 5 inch by 2.5 inch with 10 gauge wall thickness.

For ladder frames the wall thickness of aluminium beams should be 50% greater than the wall thickness of steel beams used in the same applications. Welding aluminium is normally much more difficult than welding steel though techniques and equipment are improving.

A good example of using aluminium beams in a ladder frame is the Lotus Elise chassis which uses two very large aluminium beams in a design that could be regarded as a sophisticated ladder frame and monocoque hybrid. The Elise chassis avoids the issues of welding aluminium by using glue to join the chassis parts.

8.0 Locost book errors

This is an attempt to list some of the known errors in the Locost book. There are several lists of errors available and they are all different so it is a good idea to check it yourself. This list is compiled from several sources on the internet. I do not know if all these statements will be appropriate for your build. I have added some notes in brackets.

Tube lengths different from the book

LA 13.4"
LB 13.4"
K3 20.2
K4 20.2
N1 27.2
N2 27.2
J1 58.0
J2 58.0
V 38.0
Y 32 and Y extension 3 (**note**: double check this for your build as an alternative exists, see below)
Y 36 and Y extension 2
X3 15.8
X4 15.8
O1 18.8
O2 18.8
O3 38.0
e 9.5
f 9.5
G1 27.1
G2 27.1
a 25
b 25
c 21.5
d 21.5
k 8.25
k 8.50 (**note** that there are two different sizes of tube k)

Note: if in doubt make the tubes longer as you can always cut a bit more off!

page 41
Second section down should show K3 and K4 set in 1"

Tube sizes
W1 and W2 shown as ¾, use 1"
TR5 and TR6 shown as ¾, use 1"
Note: I can't see why these sizes are regarded as errors, other than the fact that these tubes are highly stressed, but they appear in one error list. Using one inch tube will certainly be stiffer and stronger.

page 47
"build a simple wooden fixture for this assembly"
Note: I'm not sure if this is regarded as an error due to it being made of wood or due to the dimensions given.

page 51
Starting at "now separately weld RU1 and RU2 to V------"should indicate 3" in from each end of V and with ends angled 10deg to get 4 1/2" rise.
"the next tube to weld is Y (42")-----"-wrong! It is 32" long to fit between RU1 and RU2 with two pcs. 3" long to join two pcs. 7 1/2" long that make up box ends of assembly.
Note: the dimensions stated here depend on how long you choose to make your tubes Y and Y extension. I'm not implying that these are the right lengths as the book and the two error lists I've found give different sizes.

page 61
slight difference in spacing of trailing arms-front is .050" closer together than rear

page 67
Do not "Drill two 7/16"(11mm) diameter holes…", holes are 3/8".
Note: I have not checked the correct hole size

page 70
shows Panhard bar on the wrong plane. Turn view 90 degrees.

page 86
When you get to page 86 go to 113-115 next, mount engine and come back to page 87 afterwards. It is really not wise to build the tunnel or locate two interior H tubes until engine is in place, then cut to fit, mark and make a sketch, and remove the engine and do it then.

Front suspension geometry

The vertical distance between the pivot points of the lower and upper ball joints for the Cortina uprights is approximately 225mm. To achieve a castor angle of 5.3 degrees the upper ball joint centre needs to be 21mm behind the lower ball joint centre.

The chassis tubes LA and LB slope backwards to offset the top wishbone and position it correctly over the pivot points of the bottom wishbone. The top wishbone dimensions on page 83 (2nd Edition) Fig 7.11 show the overall width to be 222mm. The distance from the left hand side to the centre of the threaded piece is 102mm, the distance from the right hand side is 121mm. The location of the centre of the top wishbone will be half the width of 222mm which is 111mm. So 102mm from one side is a 9mm offset from the centre, (111 -102 =9mm). This offset is less than the 21mm required to give a castor angle of 5.3 degrees.

To try and rectify the problem some compensation can be made by offsetting the suspension mount points. This could be done by moving the lower mounts further forwards and moving the top mounts back until the desired 21mm offset is achieved.

Check your suspension design by making full size drawings of the front suspension mount positions. Use the drawings to check that the offset on your chassis is correct, that the mounts will fit properly onto the chassis tubes and that there is adequate clearance for the spring and damper units.

With the book design many builders report that the suspension brackets hang off the sides of tubes LA and LB. Some builders have altered the angle of tubes LA and LB to move the suspension mounts to the correct positions. This will affect the fitting of the nosecone. Other builders have altered the wishbones. This will affect the clearance required for the spring and damper units.

Some builders report that FU1 and FU2 need to be moved inwards to get the correct suspension mounting positions. If tubes S and T are made of 1.5 inch wide tubing then the FU tubes can be positioned near to the outer ends of these tubes instead of connecting to the J tubes. A further modification is possible. If tube LC is made 22 inches wide with ends cut at right angles then the top of assembly L is the same width as the front of the chassis. Tubes FU1 and FU2 can then be moved to be at the same angle and position as tubes LA and LB when viewed from the front of the chassis. This creates a better appearance to the front of the car and places the suspension mounts on the same plane so that the relationship between the front chassis tubes and suspension mount positions is simplified. If you make this modification then the suspension wishbones and the nosecone will need to be altered to suit the new tube positions.

9.0 Suspension Geometry

This is a summary of suspension geometry values for various cars. These values come from a variety of sources. If you spot a mistake let me know.

MX5 / Miata

Front suspension
roll centre height 61mm
camber gain in bump 0.91 degrees per inch mean rate
Scrub radius is zero

Rear suspension
camber gain in bump 0.21/0.58 degrees per inch initial/final rate
Passive rear steer toe in under cornering loads

Roll at 0.7g is 3.4 degrees (4.9 degrees per g)

Suggested suspension settings-
Static camber –0.625 front / -0.875 rear
Castor more than 5 degrees
Toe in 1/16inch front and rear

Lotus Elise

Front suspension
roll centre height 30mm
travel 50mm bump / 60 mm rebound
camber gain in bump 0.31 degrees per inch
frequency 90cpm
KPI 12.0 degrees
Castor 4.25 degrees
Trail 4mm
Scrub radius 10.5mm

Rear suspension
roll centre height 75mm
travel 50mm bump / 70 mm rebound
camber gain in bump 0.45 degrees per inch
frequency 98cpm

MGF and Ford Focus

Passive rear steering provides toe in on bump

Mc Laren F1

Front suspension
travel 90mm bump / 80 mm rebound
frequency 85cpm

Rear suspension
travel 90mm bump / 80 mm rebound
frequency 105cpm

De Dion Axle Caterham

Front suspension
roll centre height 60mm

Rear suspension
roll centre height 120mm

Experimental Caterham (Independent rear suspension)

Front suspension
roll centre height 30mm

Rear suspension
roll centre height 65mm

Mazda RX8

Front suspension
roll centre height 68mm
upper arm 8.46 inches
lower arm 13.35 inches

Rear suspension
roll centre height 96mm
upper arm 11.4 inches
lower arm 20.83 inches

Low roll centres contribute to good handling for a car with a low centre of gravity, low roll angles and driven on smooth road surfaces. Very low roll centres can be very sensitive to suspension movement and to roll. The values stated above show that the Elise and the experimental Caterham have front roll centres of 30mm. For a home built car a slightly higher front roll centre of 35 to 40mm may be better as it will be less sensitive to build tolerances. Rear roll centres are normally higher than front roll centres. The list of suspension data above will give an indication of how high a rear roll centre should be.

To calculate an appropriate spring rate you will need to choose a suspension CPM and use that to calculate the spring rate. The suspension CPM or cycles per minute is the natural frequency of the suspension.

CPM values for fast road cars typically lie in the range 85 to 110. It is usual to have a CPM about 10 to 15 CPM higher at the back than the front. The theoretical best results are for equal roll stiffness front and rear. With lower spring rates at the front a front anti roll bar is normally required to get this result.

The first value you will need to know is the sprung weight at the corners of the car. The sprung weight is the total weight on each corner minus the unsprung weight at that corner.

Unsprung weight is the weight of the parts that move relative to the chassis when a wheel goes over a bump. For an independent suspension unsprung weight will be a wheel, a tyre, a hub, an upright, a brake disc and calliper (or a drum brake) and half the suspension links and drive shaft weight for one side of the car. For a live axle it will be a wheel, a tyre, half the live axle, a drum brake and the suspension links for one side of the car.

For a Locost front suspension the corner weight may be about 375lbs with you in the driving seat.

The unsprung weight may be about 55lbs which gives a sprung weight of 320lbs.

The CPM formula is

$$CPM = 187.8\sqrt{\frac{wheelrate}{sprungweight}}$$

$$wheelrate = springrate \times (leverage)^2 \times \cos ine(springangle)$$

The spring leverage is calculated by the position of the shock absorber mounting on the wishbones. Two distances are required. The first is the distance from the wishbone chassis mount centres to the centre of the spring mount on the wishbone. The second is the distance from the wishbone chassis mount centres to the wishbone hub mount centres. The leverage is the first distance divided by the second distance.

For a live axle the two distances are, for the first, from the opposite tyre centre to the spring mount centre on the axle casing and, for the second, the distance between the tyre centres on each side of the axle.

For the Locost front suspension the distance from the wishbone chassis mount centres to the centre of the spring mount on the wishbone is about 9.1 inches. The distance from the wishbone chassis mount centres to the wishbone hub mount centres is about 13.4 inches. The ratio of the leverage is consequently about 0.68.

The springs, for this calculation, are mounted at 40 degrees from the vertical.

For the book suggestion of a 210lb spring the wheel rate is therefore 74lbs

The CPM is therefore about 90

For a Locost rear suspension the corner weight may again be about 375lbs with you in the driving seat.

The unsprung weight may be about 65lbs (live axle) which gives a sprung weight of 310lbs.

The ratio of the leverage is about 0.85 (using the opposite wheel as the suspension pivot for a live axle) and the springs are mounted vertically.

For the book suggestion of a 190lb spring the wheel rate is 137lbs

The CPM is therefore about 125

This suggests that the book Locost has a very stiff rear suspension and may benefit by either a softer spring rate at the rear or an anti roll bar or stiffer springs at the front. Several builders have reported fitting stiffer front springs, in the range of 275 to 300 lbs per inch, which may be due to heavier engine options. The stiffer spring rates result in a CPM of about 104 for the front.

Making some assumptions regarding the suspension and working through the calculations given in Alan Staniforth's book "Competition car suspension" result in a front spring rate of 210 (as in the book) and a rear rate of 140 to 130lbs with a front anti roll bar of about 10 or 11mm diameter. A stiffer choice, from the same calculation methods, is 280 front, 180 rear and a half inch anti roll bar at the front.

One builder reports good results with 275 front, 175 rear and a hollow half inch 16gauge tubular anti roll bar at the front. This is very close to the stiffer setting calculated above.

Note that these calculations will be different for your build as it is very unlikely that I have used exactly the same dimensions, weights and spring rates as you have. It is for you to determine the correct rate for your build, all I can give is an example of how I'd do it for myself.

One important point is that the front lower wishbone is very highly loaded. The book specifies a three quarter inch tube which is only suitable for smaller and lighter engines. I suggest that one inch tubes would be better. This is a simple change to the book design. There are two further changes that will improve the wishbone design but these will involve significant alterations to the design and you may wish to avoid them to keep your build simple.

If you redesign the wishbone then there are two changes that will improve the design. The book design has a distance from the lower hub pivot to the spring mount of 4.3 inches. A smaller distance is better. Some designs have a distance from the lower hub pivot to the spring mount of about two inches. The best shape for the wishbone is a V shape. The tubes of the book wishbone do not form a V shape. The tubes should be positioned on a line connecting the chassis bush centres with the lower hub pivot. In the book the tubes are offset at the outer ends to allow for the width of the lower ball joint mounting plate.

10.0 De Dion tubes

De Dion tubes are loaded by the reactions at the tyre contact patch applying a bending load on the tube ends. It is possible to estimate these loads.

Assuming a car weight, including driver, petrol, water etc, of 700Kg (1540lbs) and a 50/50 weight distribution the weight on the rear axle will be 770lbs. On each rear wheel the load will be 385lbs.

Assuming that the De Dion tube centre line is 5.5 inches back from the wheel centre line and 11.5 inches above the road then the distance from the tyre contact patch to the tube centre will be 12.75 inches.

Assuming that a bump or hollow in the road surface subjects the suspension to a lateral 3g acceleration when hit during cornering.

These are all values which may or may not apply to your car.

We now have a bending moment of 385 x 12.75 x 3 = 14726 inchlbs for the above conditions

I have calculated the required yield strength stress to take a 3g lateral load using the Secant formula. The table shows stresses for various weights over the rear axle and various tube sizes. The first two rows show tube sizes and cross sectional areas. The rest of the table gives stress in psi for the total weight on the rear axle in the left column.

Weight over rear axle	Tube size and cross sectional area (inch^2)					
	3.00-14g	3.00-16g	2.50-14g	2.50-16g	2.25-14g	2.00-12g
	0.734	0.590	0.608	0.490	0.545	0.619
	Required yield stress to take a 3g lateral load (psi)					
300Kg	25538	31430	37027	45421	45991	46809
325Kg	27666	34049	40112	49206	49824	50709
350Kg	29794	36668	43198	52992	53656	54610
375Kg	31922	39287	46283			
400Kg	34050	41906	49369			
600Kg	51076					

Using the example above a 700Kg car with 50/50 weight distribution and a De Dion tube of 3.0 inches OD and 16 gauge wall thickness would require a tube yield strength stress of 36668 psi. As the yield stress of steel tube is usually over 50000 psi this gives a minimum safety factor of about 1.36.

Obviously the big question is which numbers are safe. This analysis makes a series of assumptions that may not apply to your build or to how you will use the finished car so the final choice of tube size is yours. The following comments will, hopefully help you choose.

One builder reports using 2.25 inch OD 14 gauge tube on a lighter car, 500Kg unloaded, with total success. This weight would probably increase to give a rear axle weight in the region of 300 to 325Kg when on the road.

The live axle of the escort, as used in the book design, is reported by builders as having a 2.5 inch OD. The wall thickness is reported by one builder as being less than 10 gauge.

One kit manufacturer is reported to have used 2.0 inch OD tube with 12 gauge wall thickness. This tube size is smaller and therefore more highly stressed than most De Dion tubes. I would suggest that a bigger tube would be better.

The yield stress of steel tube is usually over 50000 psi and some permanent deformation or, eventually, collapse will occur above this stress. Consequently you may wish to use tubes that have a working stress of less than 50000 psi in the table. This working stress is exceeded for some tube sizes reported as being acceptable using my assumptions for loads. There are several reasons for this. It is possible that my assumptions about loads are too high. The experience may be based on cars that never experienced a 3g lateral load but would have problems if they had. The experience may be based on cars that were experiencing some deformation but this was never noticed as it did not become obvious. The tubes used may have been made of steel with a yield strength stress higher than 50000 psi. Several link arrangements are used for live axles and De Dion axles.

The Locost book design is a five link system consisting of four trailing links and one lateral link.

The Caterham De Dion design uses two upper trailing links and one lower link. The lower link is a large V shaped wishbone with the centre of the V connecting to the middle of the De Dion tube and the ends of the V connecting to the chassis sides by brackets on tube B1. The V shaped link will need to avoid the differential as the suspension moves. The lower V link should be at the same height as the lower chassis tubes. This gives the lowest possible rear roll centre.

A possible solution is to use a Satchel link. This link system uses four links. It does not require a wishbone or an extra link to make it work. This arrangement consists of two upper trailing links and two angled lower links. The lower links are angled to provide lateral location. The lower links normally connect the ends of the De Dion tube to the sides of the rear of the transmission tunnel by brackets on tube B1. The lower links should be at the same height as the lower chassis tubes. This gives the lowest possible rear roll centre. The lower links become very highly stressed if they are angled less than 30 degrees to the rear axle line. If the links are angled so that the outer ends are 20 inches further out and 11.5 inches further back than the inner ends then the angle of the links to the axle line will be 30 degrees. These dimensions could be achieved with a straight De Dion tube behind the rear axle with the lower link mounts on brackets at the ends of the tubes.

11.0 Internet resources

Try these websites for further information.

A lowcost discussion group. A lot of information has been posted on this site. Try the search facility.
http://www.locostbuilders.co.uk/

This site is about the creation of a new kit car called the Meerkat. A lot of information about bodywork.
http://www.desicodesign.com/meerkat/

This site is about the creation of a bike engined car. The design features a good example of a space frame chassis.
http://www.projectlmp.com/

The McSorley site has a lot of information regarding the lowcost car. The site includes a downloadable set of drawings and a cutting list for chassis tubes.
http://www.mcsorley.net/locost/

This site shows the design and build of a unique Seven style car.
http://www.geocities.com/MotorCity/7630/index.html

This site is about the creation of a mid engined car.
http://www.kimini.com/

This site is a comprehensive build diary of a mid engined car. Bodywork and chassis design is featured.
http://www.grabercars.com/Mambosite/index.php

This site is especially handy for Australian builders of the lowcost and contains plenty of handy information for lowcost and special car builders.
http://locost7.info/

Modifications to the Ultima chassis to improve its torsional stiffness are dealt with on this site. It is interesting to see how effective adding bracing around the engine bay is.
http://www.ultimav12.ca/

A lowcost discussion group
http://groups.yahoo.com/group/Locost_Theory/

A listing of part weights is given on this site for Seven type cars
http://www.fluke-motorsport.co.uk/weight/index.html

This forum includes a kit car section.
http://www.pistonheads.com/gassing/

This site contains a lot of information about a car build project.
http://www.statikdesign.com/scratchbuilt/